RESEARCH DEPARTMENT

A field-store converter using ultrasonic delays as the storage medium

RESEARCH REPORT No. T-136

1964/65

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

A FIELD-STORE CONVERTER USING ULTRASONIC DELAYS AS THE STORAGE MEDIUM

Research Report No. T-136
(1964/65)

D. Maurice

(R.D.A. Maurice)

W. Wharton, A.M.I.E.E.
E.R. Rout, A.M.I.E.E.
R.E. Davies, M.A.

Research Report No. T-136

A FIELD-STORE CONVERTER USING ULTRASONIC DELAYS AS THE STORAGE MEDIUM

Section	Title	Page
	SUMMARY	1
1.	INTRODUCTION	1
2.	THE BASIC PROCESS OF FIELD-STORE CONVERSION USING A DELAY STORE	2
3.	A PRACTICAL FIELD-STORE CONVERTER	4
4.	THE DEVELOPMENT OF A FIELD-STORE CONVERTER	6
	4.1. Preliminary Studies	7
	4.1.1. Movement Portrayal	7
	4.1.2. Interpolation	7
	4.1.3. Specification of Delays	8
	4.2. Development Work	8
5.	FURTHER DEVELOPMENT	9
6.	CONCLUSIONS	10
7.	REFERENCES	10
	APPENDIX I	11
	APPENDIX II	14
	APPENDIX III	18
	APPENDIX IV	28

October 1964

Research Report No. T-136

(1964/65)

A FIELD-STORE CONVERTER USING ULTRASONIC DELAYS AS THE STORAGE MEDIUM

SUMMARY

In this report, the conversion of television pictures between standards having different field frequencies is discussed and a method is proposed whereby a standards converter capable of conversion between the British 625-line/50 fields and American 525-line/60 fields standards could be realised by the use of ultrasonic delays. Such a standards converter would have a performance superior to that of the cathode-ray tube/camera combination at present used for conversion between the British and American standards.

1. INTRODUCTION

New methods of conversion from a television standard using one number of lines in a picture to a second standard using a different number of lines in a picture have recently been developed.[1,2,3] Standards converters based on these new methods use assemblages of electronic switches and passive network storage elements which have sufficient capacity to write, read and store a whole line of a television signal. These new standards converters, which can be conveniently termed 'line-store' converters, have a performance significantly superior to that of the cathode-ray tube/camera combination (subsequently referred to as an image-transfer converter) at present in use and, unlike the latter, require very little routine maintenance and adjustment.

The line-store type of standards converter is limited in application in that it is only able to convert between television standards in which the field frequencies are identical. One of the authors[4] has, however, proposed a method of conversion between television systems with different field frequencies by means of switched delays. Such a standards converter can conveniently be termed a 'field-store' converter. There are several possible applications for field-store converters, but in this report, apparatus suitable for only one application is considered; namely, conversion between the British 625-line/50 fields and American 525-line/60 fields systems (for convenience, throughout this report, these systems will be referred to as the 625/50 and 525/60 standards).

In a conversion which requires that the number of fields per second be increased, it will be necessary to compress the duration of the input standard fields

and to add in additional fields. Conversely, if the number of fields per second is to be decreased, it will be necessary to expand the duration of the input standard fields and to omit fields. Both these processes demand the ability to store up to a complete field at the input standard for varying periods of time and this requires a storage capacity some two or three hundred times greater than that provided in a line-store converter. From the practical point of view at the present time, only magnetic recording devices such as the disc store[5] and ultrasonic delays[6] offer sufficient storage capacity without unacceptable deterioration of the video signal. Of the two methods, the fused-quartz ultrasonic delay offers the required performance (particularly with regard to noise) with more certainty and only this type of delay will be considered here. Nevertheless, disc stores merit further consideration since, if the performance could be improved sufficiently, they would provide the larger delays required more cheaply.

In this report a field-store converter using a number of fused-quartz ultrasonic delay lines as the storage medium is proposed. Since a complete description of a field-store converter requires a rather detailed analysis, an outline explanation only is given in the body of this report, together with a discussion of the feasibility of a practical design using fused-quartz delays as the storage medium. A full description of the principles of field-store conversion and the operation of the proposed field-store converter is however given in the four appendices to this report:

Appendix I - The basic process of field-store conversion using a delay line with sliding tap.

Appendix II - Field-store conversion using arrangements of switched fixed delays.

Appendix III - Conversion between the British 625/50 and American 525/60 standards.

Appendix IV - The correction of timing errors in the output signal.

It should be mentioned that two main forms of practical converter are proposed. The first, and simpler, form of converter is capable of conversion only when the two field frequencies are maintained accurately at 50 and 60 cycles/second. The second, and more advanced, form of converter incorporates a modified form of line-store converter and would accept signals whose field frequencies are not locked; either or both field frequencies could, in fact, depart appreciably from their nominal values. For convenience, the explanation of the principles of the proposed converter is made in terms of the first, and simpler form. The second, and more advanced form is, however, discussed in Section 5 of this report.

2. THE BASIC PROCESS OF FIELD-STORE CONVERSION USING A DELAY STORE

The basic process of field-store conversion is described in Appendix I; in this Section, however, a simplified account of the process is given. For the purposes of explanation, Fig. 1 shows a simple system which could theoretically be used to convert between two television systems that have different field frequencies. The arrangement consists of a delay* capable of storing one complete field at the input

* In order to avoid confusion, a delay line used to store television signals will be referred to as a 'delay'. The word 'line' will only be used to refer to a scanning line of a television signal.

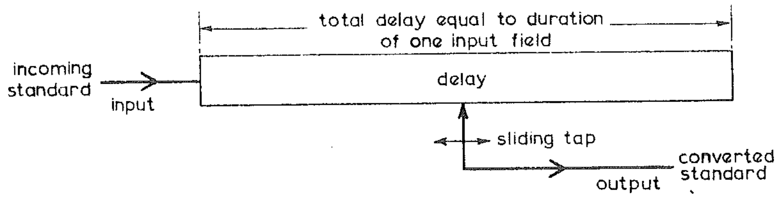


Fig. 1 - Field-store conversion by delay with sliding tap

standard. The input standard is applied to the input of the delay and the output standard (the converted picture) is taken from a sliding tap. If the sliding tap is moved from the input of the delay (i.e. the point of zero delay) towards the far end, then the output from the tap will comprise television fields whose duration has been increased. Each input field will appear at the terminals of the sliding tap expanded in time and the number of output fields per second must therefore be less than the number of input fields; it will therefore be necessary at intervals to omit a complete input field. Thus, for example, if the conversion were from a 60 fields/second to a 50 fields/second standard, it would be necessary to omit every sixth field. The tap would traverse the delay in the duration of six input fields (giving five output fields whose duration is expanded in the ratio 6 : 5). At the conclusion of the fifth output field, the sixth input field would be completely stored in the delay and could be omitted by switching the sliding tap back to the input of the delay.

A delay with sliding tap could also be used to convert from one standard to another having more fields per second. In this case, the tap would move from the end of the delay back towards the input, thus compressing the input fields in time. Since the number of output fields occurring every second will now exceed the number of input fields, it will be necessary at intervals to generate the missing output field by a repetition of one of the input fields. For example, in the case of conversion from a 50 fields/second to a 60 fields/second standard, the first input field would first be stored in the delay. The sliding tap would then traverse the delay during the duration of the next five input fields, giving six output fields whose duration is compressed in the ratio 5 : 6. At the conclusion of the sixth output field, the sixth input field will be completely stored in the delay and can be 're-read' by switching the sliding tap contact to the far end of the delay and re-commencing the cycle.

In the arrangement described, the number of fields per second would be converted, but the number of lines in the input and output pictures would be identical. In general, however, it is necessary to convert between standards in which both the number of fields per second and the number of lines per field are different. One solution of this problem would be to follow the delay with sliding tap by a line-store converter. Thus, for example, a conversion from the American 525/60 standard to the British 625/50 standard could be carried out in two stages. The delay with the sliding tap would convert from the 525/60 standard to a 525/50 standard and the line-store converter would convert from the 525/50 standard to the 625/50 standard. It would, however, be possible to carry out the complete conversion using the delay with sliding tap alone without an additional line-store converter. Since the number of lines per field and the number of fields per second must both be changed, the conversion must involve the omission or addition of lines in each field, and the addition or omission of fields. These processes could be achieved if the sliding tap on the

delay of Fig. 1 were moved discontinuously. For example, if the conversion were from an input 625/50 standard to an output 525/60 standard, it would be necessary to omit 50 lines from each input field and in addition to duplicate every fifth input field. During the period of each line at the output standard, the sliding tap would move towards the input of the delay at such a velocity that the duration of the line would be compressed from 64 μs (the British 625-line standard) to $63\frac{31}{63}$ μs (the American 525-line standard). Each time an input line had to be discarded, the tap would 'jump' towards the input of the delay so that the total delay between the input and the tap would be reduced by 64 μs, thus omitting the line stored in that section of the delay. This movement would continue throughout the duration of a cycle of five input fields, during which time the tap would have travelled back from the end to the input of the delay. The tap would then be switched back to the end of the delay to re-commence the cycle and would provide the sixth input field by a repetition of the fifth input field, which would be at that moment completely stored in the delay. A similar arrangement could be used for the converse case of conversion from the 525/60 standard to the 625/50 standard.

The delay with its sliding tap moved discontinuously would convert both the number of fields per second and the number of lines per field correctly. The displayed picture of the output standard would, however, be distorted on account of the discontinuities resulting from the omission or repetition of lines of the input standard. This distortion could, however, be eradicated by the use of the technique of interpolation employed in one of the forms of line-store converter.[2,3]

3. A PRACTICAL FIELD-STORE CONVERTER

It is pointed out in Appendix II that although the arrangement described in the previous Section indicates the basic principle employed in field-store standards conversion, it cannot be realised in practice since, at the present time, it is not possible to construct a satisfactory delay with a sliding tap. It must, however, be remembered that the tap is required to move continuously only in order to expand or compress the duration of each line of the input standard to the duration required by the output standard. The operations of omitting or adding lines and omitting or adding fields require only that the tap should move in discrete steps. If therefore the duration of the lines on the two standards were identical, it would be possible to realise a practical field-store converter using fixed sections of delay in conjunction with a suitable switching arrangement in place of the delay with sliding tap; the operation of such an arrangement is described in Appendix II. The output of such a converter would be correct as regards both field frequency and number of lines, but would, of course, need the addition of an interpolator to correct distortion of the output display due to the omission or addition of lines.

In Appendix III, the particular case of conversion between the 625/50 and 525/60 standards is discussed, and it is pointed out that although the line durations of the two standards are not identical, they are very similar (64 μs and $63\frac{31}{63}$ μs respectively). As a result, a field-store converter using switched delays could be designed which would require only a small adjustment of the line length in order to give a correct conversion. The small adjustment of line duration would require only a small storage capacity which could be provided by a relatively simple form of variable delay. This delay could take the form of a conventional lumped element

network in which biased diodes are used as the shunt capacities; such a delay (the 'Amtec') is, in fact, used in the Ampex video-tape recorder. Alternatively, a store similar to that employed in a line-store converter could be used;[1,2,3] this might be an acceptable solution since only about 60 storage elements would be needed instead of the 600 required for line-store standards conversion. Correction of the timing of the output signal is discussed in Appendix IV and it is pointed out that in addition to the need to adjust the duration of the output scanning lines, errors of timing due to errors in the individual fused-quartz delays and further timing errors due to variation in the incoming line frequency will need correction.

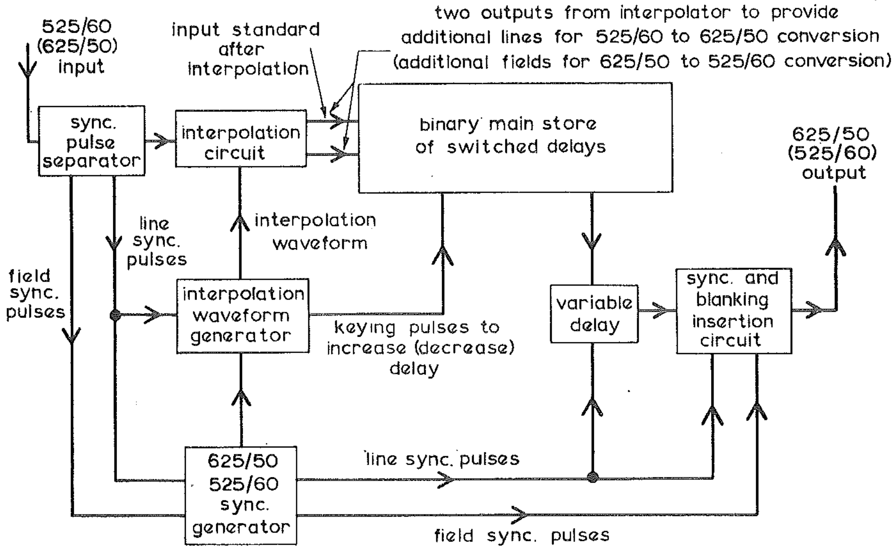


Fig. 2 - Schematic of basic field-store converter

Note. The circuit is drawn for conversion from 525/60 to 625/50
The changes in caption for conversion from 625/50 to 525/60 are shown in brackets

Fig. 2 shows a block schematic diagram of a possible form of field-store converter[4] using a series of switched fixed delays. The operation of this converter is described in detail in Appendix III. The input signal is first passed through an interpolating network which compensates for errors which will be introduced by the omission or repetition of lines. The output from the interpolating arrangement is then passed through the main store* which consists of an arrangement of fused-quartz delays which are switched to omit or add lines and omit or add fields as required. Finally, the output of the main store is passed through a variable delay which adjusts the duration of the lines to the duration required by the output standard. This delay would be controlled by the difference in timing of the lines emerging from the main store and the timing of correctly-timed synchronising pulses at the output standard.

* It is convenient to use the term 'main store' to denote the arrangement of switched fixed delays. This avoids confusion with the variable delay used for adjustment of line length to that required for the output standard.

The main store will have a total delay equal to the duration of one field at the input standard and will be equivalent to a continuous delay tapped at regular intervals approximately equal to the duration of one line. It is important to realise, however, that the interval of delay between taps will not be exactly equal to the duration of a line on either standard. The conversion process requires that the number of increments of delay is equal to the number of lines which must be added or omitted during one complete cycle of the process. This is equivalent to saying that the increment of delay between taps must be equal to:

$$T = \frac{\text{difference in field durations of the two standards}}{\text{difference in number of lines per field of the two standards}} = 66\tfrac{2}{3}\ \mu\text{s}$$

The number of these units of delay (i.e. the number of tapping points) will thus be the total delay of the main store divided by $66\frac{2}{3}\ \mu$s and this gives:

$$\frac{1}{50} \times \frac{10^6}{66\frac{2}{3}} = 300 \text{ units for 625/50 to 525/60 conversion}$$

$$\text{and } \frac{1}{60} \times \frac{10^6}{66\frac{2}{3}} = 250 \text{ units for 525/60 to 625/50 conversion}$$

Although the fused-quartz delay arrangement used for the main store must be equivalent to 250 or 300 sections connected in cascade, each with a delay of $66\frac{2}{3}\ \mu$s, such an arrangement would be extremely difficult to engineer in practice. A binary arrangement of delays with appropriate switching would therefore be used, since this would enable the same functions to be performed by a small number of fixed delays. In the worst case, for conversion from the 625/50 to the 525/60 standard, a binary delay would require nine sections with delays of T, $2T$, $4T$ ..... $256T$ where T is $66\frac{2}{3}\ \mu$s. However, this arrangement would be somewhat extravagant since delays of up to $511T$ would be available, and it would be possible to replace the '$256T$' delay by a '$45T$' delay to make a total delay of exactly $300T$.

For the sake of simplicity, no mention has yet been made of interlacing, which has two principal consequences; successive fields are not identical, and each contains an odd number of half lines. However, account can be taken of these facts in the design of the interpolator. As illustrated in Fig. 2, two different interpolated signals would be generated simultaneously and these would be supplied to different points in the binary arrangement of delay units that replace the tapped delay. In addition, a delay equal to one-half of a line period at the input standard is switched into circuit each time a field is added or omitted to avoid identical successive fields. The operation of the interpolator and main store are, however, described in detail in Appendix III.

4. THE DEVELOPMENT OF A FIELD-STORE CONVERTER

Although the field-store converter outlined in Section 3 is theoretically capable of giving a performance superior to that of an image-transfer converter, in practice the operation may be limited by instrumental difficulties and at the present time it is impossible to guarantee that an adequate performance can be obtained.

It is therefore necessary to carry out various preliminary studies before proceeding to more detailed development work. Thus the work required to establish the feasibility of the field-store converter and to realise such a converter in an operational form falls under two headings - preliminary studies and actual development work.

4.1. Preliminary Studies

4.1.1. Movement Portrayal

A conversion between standards having different field frequencies must degrade the portrayal of movement. In the converter proposed here, steady movement in the original scene would be converted into jerky movement, each jerk being occasioned by the duplication or omission of one of the incoming fields. An image-transfer converter also portrays steady movement as jerky movement, but this effect tends to be masked by the smear resulting from the use of a cathode-ray tube with a long afterglow and from imperfect erasure in the camera; the camera in such a converter is subject to photo-conductive lag if a vidicon tube is used and this results in further smearing. Image-transfer converters developed in Research Department using a C.P.S. Emitron camera tube and a cathode-ray tube afterglow time constant of about 10 ms produce movement jerks that are just perceptible. The same type of converter with a cathode-ray tube having a time constant of about 3 ms produces movement which is more jerky and less smeared. In the case of the Fernseh converter, however, (using a vidicon camera tube) the smearing is such that jerks are quite imperceptible.

Experience with the various converters suggests that the jerky movement produced by a field-store converter will not be sufficiently annoying to counterbalance the advantages of this type of converter; it is nevertheless essential that this point be checked experimentally.

One method of investigation of jerky movement is to expose a film at 50 or 60 fields-per-second and then step-print so as to duplicate every fifth field in the former case or omit every sixth field in the latter case. The film would then be projected at 60 or 50 fields-per-second as appropriate. An alternative method entails the use of a slide scanner with a perturbed line scan to simulate the effect of panning. Work is in hand to simulate and assess the effects of jerky motion by both of these methods.

4.1.2. Interpolation

In a line-store converter, interpolation results in spurious moire patterns which can cause a perceptible degradation of the picture, particularly when vertical motion occurs in the transmitted scene. The proposed field-store converter would produce a similar effect, but the spurious components would alternate in phase at 5 c/s even if the scene were quite stationary.* Thus, for example, the appearance of a sloping edge would change at 5 c/s and this could result in an annoying flicker. It seems likely that interpolation will require to be performed much more perfectly than in the case of a line-store converter if this effect is to be reduced to a

* The writers are indebted to Mr. P. Rainger of BBC Designs Department for drawing attention to this effect.

tolerable level. Work is in progress to simulate the effect by perturbing the field scan of a slide scanner and passing the resulting signal through an interpolator of the type proposed and these experiments will enable different interpolation laws to be studied.

4.1.3. Specification of Delays

Errors in the delay of the elements of the main store will clearly affect the timing of the outgoing scanning lines and experiments are therefore in progress to determine the accuracy with which the timing of the commencement of the lines must be corrected. Experiments are also being performed to determine the tolerance to errors in amplitude/frequency characteristic, linearity and other characteristics associated with fused-quartz delays, bearing in mind that these errors will vary periodically at 5 or 10 c/s.

When the performance of the main store has been specified, it will be necessary to determine the best method of modulation and to produce a specification for the performance of the fused-quartz delay blocks with their transducers. This specification will, of course, depend on the modulation system chosen. Fused quartz delay units giving delays of the required magnitude and capable of transmitting a television signal are at present available and the principal problems will be to achieve the necessary high stability of gain, the necessary low level of spurious signals due to reflections and the high degree of linearity required.

4.2. Development Work

If the preliminary studies discussed in Section 4.1. indicate that the proposed field-store converter is feasible, it will be necessary to develop a prototype of the basic converter (i.e. the converter proposed in Section 3, in which the input and output field frequencies are stable and have the precise ratio 5 : 6). This development work can be divided as follows:

(i) The preparation of a complete outline design.

(ii) The design of the fused-quartz delay units of the main store and their associated temperature-stabilising ovens,* amplifiers, and of modulating equipment.

(iii) The design of the timing corrector.

(iv) The design of the switching circuits which, in association with the fused-quartz delays, will perform the operations of repeating or omitting lines and fields of the input standard.

(v) The design of the interpolating arrangements necessary to remove geometrical distortion of the picture caused by the omission or repetition of lines.

* If these are not supplied by the manufacturer

5. FURTHER DEVELOPMENT

The field-store converter proposed in Section 3 would be suitable for applications in which the input and output field frequencies are precisely in the ratio 5 : 6 or 6 : 5 and are maintained accurately at 50 or 60 cycles/second. The proposed converter would thus be suitable for applications in which either the input (or output) field frequency could be regarded as the master and derived from a stable source; the output (or input) field frequency would then be derived from it. The proposed converter would *not* convert mains-locked signals, but it should be noted that mains-locked signals recorded on video tape could be re-played locked to a stable source. If, however, a modified line-store converter were incorporated in place of the simple variable delay described in Section 3, and shown in Fig. 2, these restrictions could be removed and the resulting device could then accept signals whose field frequencies are not locked in the ratio 6 : 5, so that either or both field frequencies could depart appreciably from the nominal values. The output of such a converter could even be slave-locked. This modification would probably increase the cost and complexity of the field-store converter and it has therefore been assumed in Section 4 of this report that it should not be included in the prototype. Apart from the need to maintain precise input and output field frequencies, the field-store converter proposed in Section 3 would have two other disadvantages:

(i) As has already been mentioned in Section 4, the use of an interpolation process similar to that used in a line-store converter[2,3] will result in the appearance of sloping edges changing at 5 c/s. This form of distortion could be overcome by the provision of a field delay in the interpolator which would make available a complete picture for interpolation purposes. Interpolation between the lines of a picture (as opposed to interpolation between the lines of a field) would considerably reduce this type of distortion and would eliminate the flickering effect referred to above since no change in the interpolation process would occur when a field is duplicated or omitted. Moreover, the vertical resolution would be improved.

(ii) As has been mentioned in Section 4, the omission or duplication of fields in the conversion process will result in a jerky portrayal of movement. The provision of a field delay in the interpolator could overcome this difficulty since it would be possible to interpolate between fields, thus providing a smooth sequence of movement without discontinuities.

It seems improbable that one and the same field delay could be arranged to perform both of the functions (i) and (ii) above (line interpolation and movement interpolation). Further, the addition of even one field delay would result in a major increase in cost and technical complexity. However, the advantages of interpolation between the lines of a picture and of movement interpolation are considerable and it is probable that they would eventually be required in an operational field-store converter.

There is little doubt that ultimately a field-store converter for the conversion of colour television pictures between the British and American standards will be required. It is not possible to make a detailed study of this aspect of field-store

conversion at the present time, however, since decisions have yet to be made regarding the system of colour television which will be used in the United Kingdom, and the precise value of the field frequency. It seems probable, however, that the form of converter proposed in Section 3 of this report could be adapted for the conversion of colour television signals.

6. CONCLUSIONS

In this report, the theory of operation and the design of apparatus suitable for conversion between the American 525-line/60 fields and British 625-line/50 fields standards are discussed. A design of converter is proposed which would use a main store comprising a number of fused-quartz delays and might have a performance significantly superior to that of the conventional image transfer converter.

It is pointed out that a number of preliminary studies are necessary to determine whether a practical design is feasible. If the results of these studies are satisfactory, it is suggested that initially a converter[4] for monochrome operation should be developed which would require the ratio of the input and output field frequencies to be precisely in the ratio 5 : 6 and maintained accurately at 50 and 60 cycles/second. It is thought likely that the design could subsequently be modified to convert between standards in which the ratio of input and output field frequencies varies. It is also probable that a design could eventually be developed for conversion of colour signals.

7. REFERENCES

1. RAINGER, P., 'A New System of Standards Conversion', I.E.E. Conference Report, Series 5.

2. LORD, A.V., and ROUT, E.R., 'An Outline of Synchronous Standards Conversion Using a Delay Line Interpolator', I.E.E. Conference Report, Series 5.

3. 'An Outline of Synchronous Standards Conversion Using a Delay Line Interpolator', Research Department Report No. T-096, Serial No. 1962/31.

4. DAVIES, R.E., BBC Patent Application No. 48370/64.

5. 'A Visit to Germany - 7th - 16th October 1963', Research Department Report No. A-081, Serial No. 1963/62, Section 4, pages 12 to 14.

6. BROCKLESBY, C.F., PALFREEMAN, J., and GIBSON, R.W., 'Ultrasonic Delay Lines', (Iliffe, 1963).

APPENDIX I

Field-Store Conversion Using A Delay Line with Sliding Tap

In Section 2 of the body of this report, an outline is given of the basic process of field-store conversion by reference to a continuously tapped delay. The design of a practical field-store converter must be based on a more rigorous examination of the basic process used in the conversion and in this Appendix, the process of field-store standards conversion using a delay line with sliding tap is examined in detail. It should, however, be pointed out that this simple system is restricted in that it can only be applied to conversion between field sequential television systems.

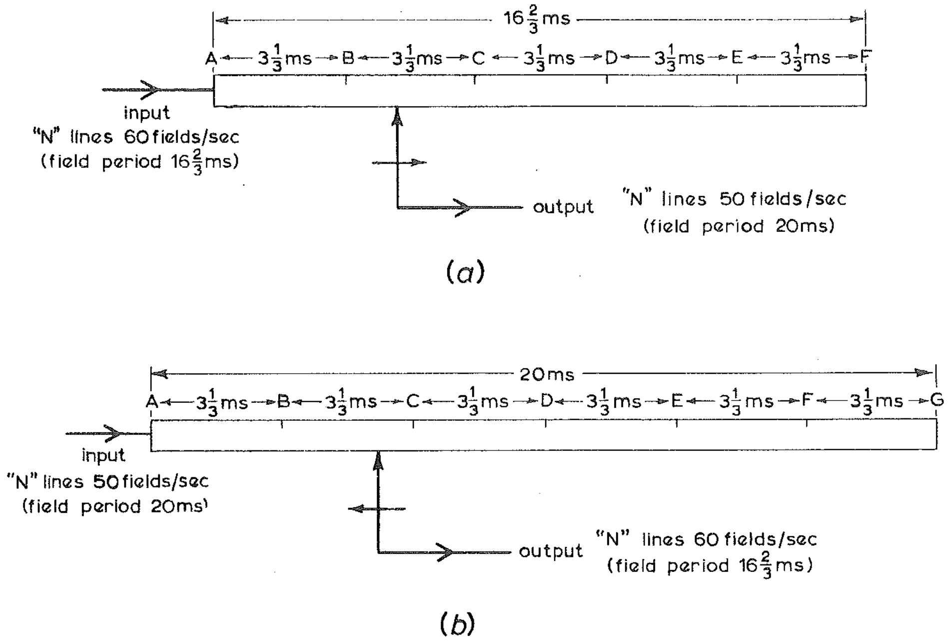


Fig. 3 - Field-store conversion by delay with sliding tap

(a) Conversion from 60 to 50 fields/second
(b) Conversion from 50 to 60 fields/second

Figs. 3(a) and 3(b) show in more detail the simple (but unrealisable) system on which the outline explanation in the main body of the report is based. It is useful, first, to consider the operation of the system when a conversion is made from 'N' lines, 60 field-per-second standard to an 'N' lines, 50 field-per-second standard (i.e. a change is made in the number of fields per second without a change in the number of lines per field). The input standard N/60 is applied to the input of the tapped line in Fig. 3(a) and the output standard N/50 is taken from the output

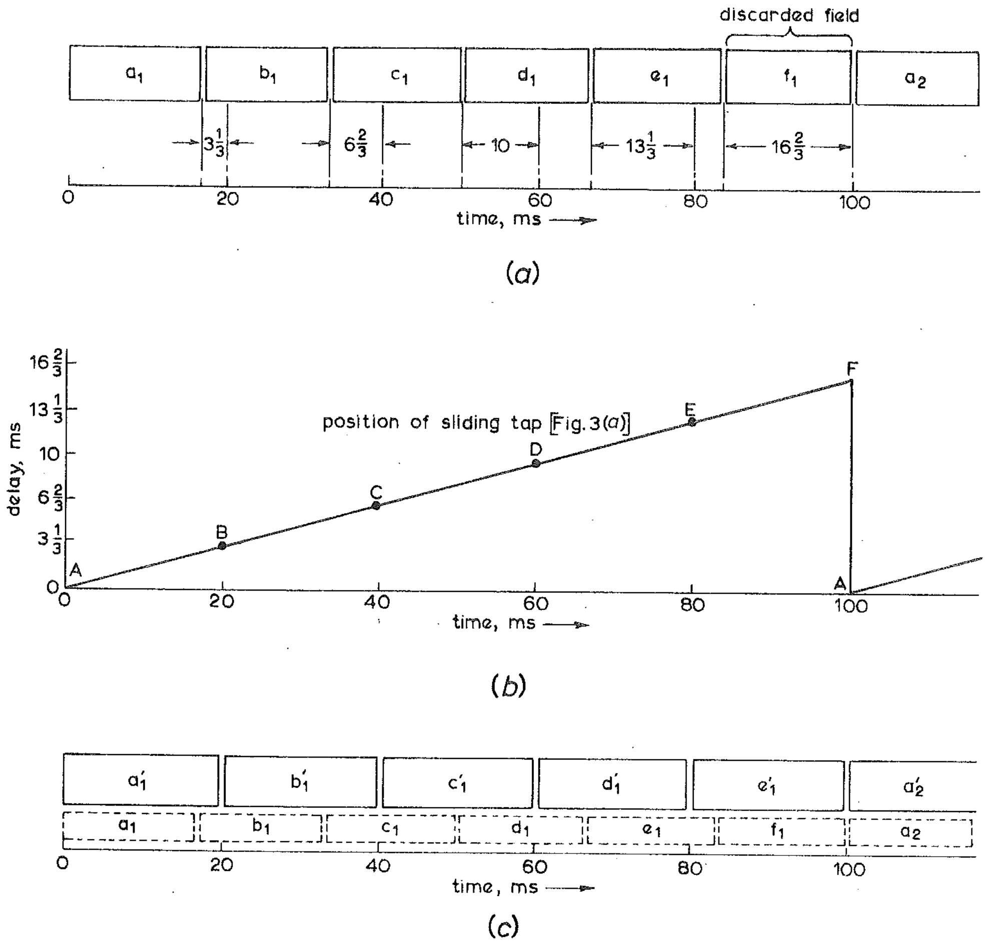


Fig. 4 - N/60 to N/50 conversion using continuously variable delay

(a) Input fields
(b) Delay introduced by sliding tap delay
(c) Output fields (input fields shown dotted for comparison)

tap. The timing of events is shown in Fig. 4 in which a sequence of six input fields is denoted 'a' to 'f'; the first cycle of six fields considered is denoted a_1, b_1 ..... f_1 and the next cycle, a_2, b_2 ..... f_2. The output field derived from a given input field is denoted by a dash; thus the output field derived from input field a_1 is a_1'.

At the start of input field a_1 (Fig. 4) the tap is at the sending end of the delay (position A in Fig. 3(a) and Fig. 4(b)). No delay is therefore introduced between input and output terminals and the start of input field a_1 coincides with the start of output field a_1'. However, input field a_1 has a duration of $16\frac{2}{3}$ ms whereas the corresponding output field a_1' is required to occupy 20 ms. Thus, if the input standard is to be converted so that it will register correctly on a picture display scanned at the output standard, the sliding tap must move so that the delay is steadily increased from zero at the beginning of the input field a_1 to an amount equal to the difference between the field periods at the end of the first output field a_1'. This difference in field duration is $3\frac{1}{3}$ ms and the sliding tap is therefore steadily moved to position B in Fig. 3(a) so as to increase the delay by this amount in 20 ms.

The second input field b_1 begins $3\frac{1}{3}$ ms before the second output field b_1' and therefore ends $6\frac{2}{3}$ ms earlier than b_1'. Thus the delay inserted between the input of the delay and the sliding tap must be steadily moved to position C in Fig. 3(a), increasing the delay by a further $3\frac{1}{3}$ ms during the period of the second output field b_1'. This addition of $3\frac{1}{3}$ ms delay during every output field period is continued for the duration of five output fields, at the end of which the delay between the input and the sliding tap is $16\frac{2}{3}$ ms (a complete field duration at the input standard). This steady increase of delay is shown in Fig. 4(b) plotted against time.

The end of the fifth output field e_1' coincides with the commencement of the seventh input field a_2. Thus every sixth input field must be discarded in order to change the field frequency from 60 to 50 fields-per-second, and this can be achieved by switching the sliding tap in Fig. 3(a) back to the point A (the input of the delay) at the end of the fifth input field. Referring to Fig. 4(a), therefore, the field f_1 (which is stored in the delay at the moment of switching) is discarded; the process is then repeated and each cycle of six input fields results in a cycle of five output fields.

A delay with a continuously variable tap may also be used to convert from a lower to a higher field frequency, once again without a change in the number of lines per field. The delay with sliding tap used for this conversion is shown in Fig. 3(b) and the associated timing diagram in Fig. 5. In this case, a sequence of five input fields is considered, the first cycle of five fields being denoted a_1, b_1 ..... e_1, and the next cycle a_2, b_2 ..... e_2. It is convenient to assume that the conversion cycle commences at the beginning of the field a_1 (i.e. that there have been no input fields prior to this time). At the commencement of field a_1, the sliding tap is in position G (Fig. 3(b)) and a delay of 20 ms is thus inserted between the input and the output of the delay. After an interval of $16\frac{2}{3}$ ms, the sliding tap has moved to a position F (a reduction in delay of $3\frac{1}{3}$ ms) and is thus coincident with the point reached in the delay by the commencement of the first input field a_1. During the next $16\frac{2}{3}$ ms, the sliding tap moves towards the input to position E, and thus gives the first output field a_1' (which is the input field a_1 compressed in time). The process is continued throughout the input fields b_1, c_1, d_1 and e_1, which appear compressed in time as the output fields b_1', c_1', d_1' and e_1'. At the end of the input field e_1, the tap has reached the point A (the input of the delay) and the field e_1 is thus completely stored in the delay at that instant. The sliding tap is therefore switched back to the point G and the field e_1 is repeated, compressed in time to become the output field e_1''. The process then continues, the next cycle commencing with the output field a_2' which is derived from the input field a_2.

APPENDIX II

Field-Store Conversion
Using Arrangements of Switched Fixed Delays

In Appendix I, field-store conversion without a change in the number of lines per field is discussed. As has been pointed out, however, the system described cannot be realised in practice since at the present time it is not possible to construct a wide-band delay with a continuously sliding tap. The continuously-tapped delay can, however, be approximated by fixed units of delay in conjunction with an arrangement of switches,* and a variable delay of this form can be used as the basis of a practical field-store converter. An increase or decrease of delay obtained by switching a fixed unit of delay into or out of the main store is likely to cause a momentary disturbance to whatever signal is passing to the output at the time of switching and in view of this, the most suitable times for switching are during the line or field-blanking periods. Conversion is required between standards that have different field durations and the conversion process thus demands that the active field duration must be changed. Since an arrangement of switched delays cannot change the duration of the lines, the active field duration must be changed by the addition or omission of lines. Thus, of the two possible times for switching and changing the delay of the main store, the line-blanking period must be used since it enables lines to be added or omitted in each field.

In a practical field-store converter, the delay increments will be made comparable to a line period at the incoming standard and switching will only occur when a line has to be repeated or omitted. The operation of such a system can be illustrated by consideration of the case of conversion from a 250/60 field-sequential standard to a 300/50 field-sequential standard. The ratio of field frequencies is the same as that of the British 625/50 and American 525/60 system, but unlike these systems, the line duration is identical on the input and output standards. In addition, the number of lines per field are close to those required by the British and American standards.

In the conversion process, one line in five of the 250/60 standard must be repeated by switching in a unit of delay equal to a line period. Each output field will thus contain 6/5 times the number of lines contained in an input field and the field duration will be increased in the ratio 6 : 5, thus resulting directly in the required output standard of 300/50. The delay of the main store will have been increased by 250 line periods over the period of six input fields. At the end of the sixth input field, the delay of the main store will be switched back to zero, thus discarding this field which will, at that moment, be completely contained in the main store.

The field-by-field operation of the arrangement is identical with that for the N/60 to N/50 conversion shown in the timing diagrams of Fig. 4. In the arrange-

* The arrangement of switched fixed delays will be referred to as the 'main store'

ment now considered, however, the delay is not continuously variable, and the smooth delay variations are 'quantised' into discrete steps, too small to be shown in the scale of Fig. 4. Fifty of these discrete steps will take place during the period of each output field, and a timing diagram for the line-by-line operation over the first 24 input lines of the first field of a cycle of six input fields is shown in Fig. 6. It will be seen that an additional delay equal to a line period is inserted in the main store at the end of every fifth output line. This causes each fifth output line to be repeated so that the converter provides six output lines for every five input lines.

When it is required to convert from the standard with a lower field frequency to the higher field frequency, the delay of the main store must be reduced throughout each field period, and the timing diagram for 'field-by-field' operation will be similar to that shown for a continuously variable delay in Fig. 5. As before, the

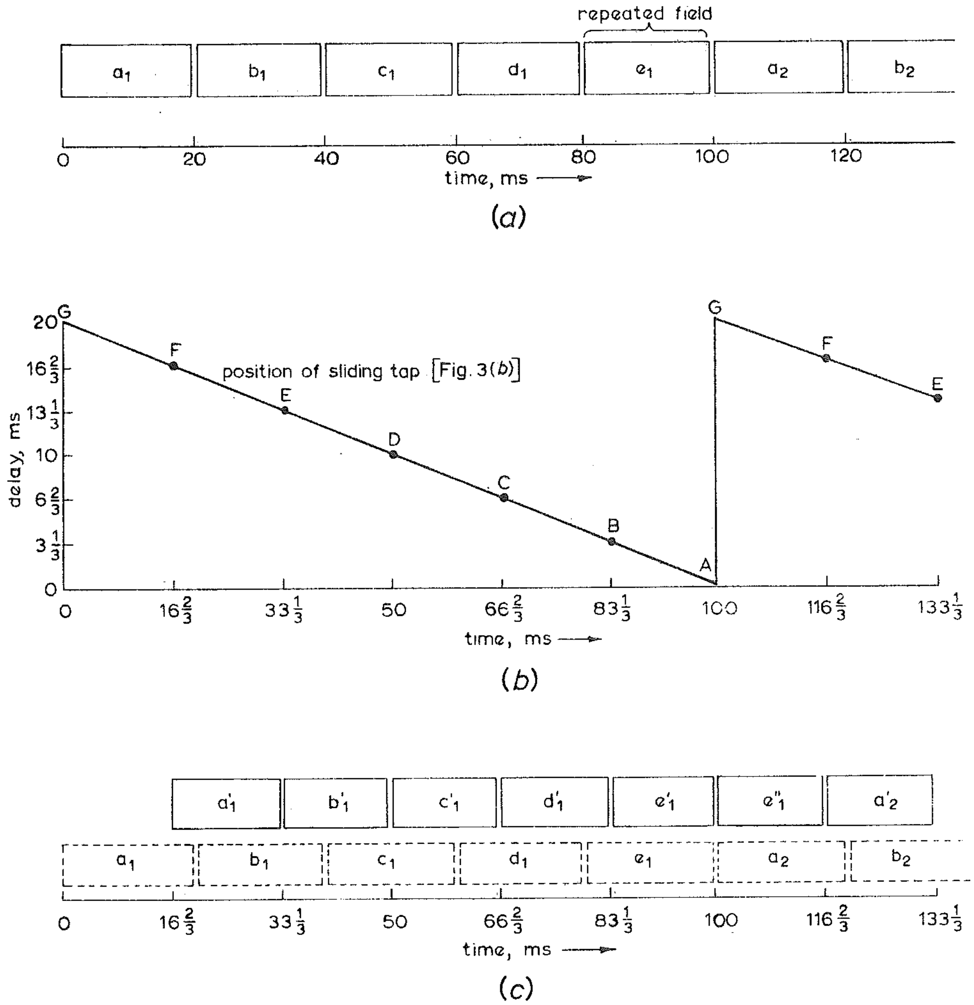


Fig. 5 - N/50 to N/60 conversion using continuously variable delay

(a) Input fields
(b) Delay introduced by sliding tap
(c) Output fields (input fields shown dotted for comparison)

total delay of the main store is required to be equal to one input field duration. The input field duration is now equal to 300 line periods, however, so that a larger store is required for 300/50 to 250/60 conversion than is required for a 250/60 to 300/50 conversion.

The conversion process described will, of course, result in geometrical distortion of the output picture due to the repetition or omission of lines. It would thus be necessary to include an interpolation process in a practical conversion. It will be seen that the arrangement described will convert between the field sequential standards in which the line durations are identical. The arrangement is therefore suitable for conversion between any two standards which satisfy the relationship:

$$\frac{L_1}{L_2} = \frac{f_2}{f_1} \tag{1}$$

where L_1 and f_1 are the number of lines-per-field, and the field frequency of one system, and L_2 and f_2 are the number of lines-per-field and the field frequency of the other system.

Since a delay change is made every time a line must be omitted or added, the number of delay changes required per field period will be given by:

$$N_D = |L_1 - L_2| \tag{2}$$

The delay increment made each time a line is omitted or added will be given by:

$$\begin{aligned} D &= \left|\frac{1}{f_1} - \frac{1}{f_2}\right| \Big/ \left|L_1 - L_2\right| \\ &= \frac{1}{L_1\ f_1} \\ &= \frac{1}{L_2\ f_2} \end{aligned} \tag{3}$$

In the case shown in Fig. 6, the line duration for both the 250/60 and 300/50 standards is:

$$\frac{1}{L_1\ f_1} = \frac{1}{L_2\ f_2} = \frac{10^6}{250\ .\ 60} = 66\tfrac{2}{3}\ \mu s.$$

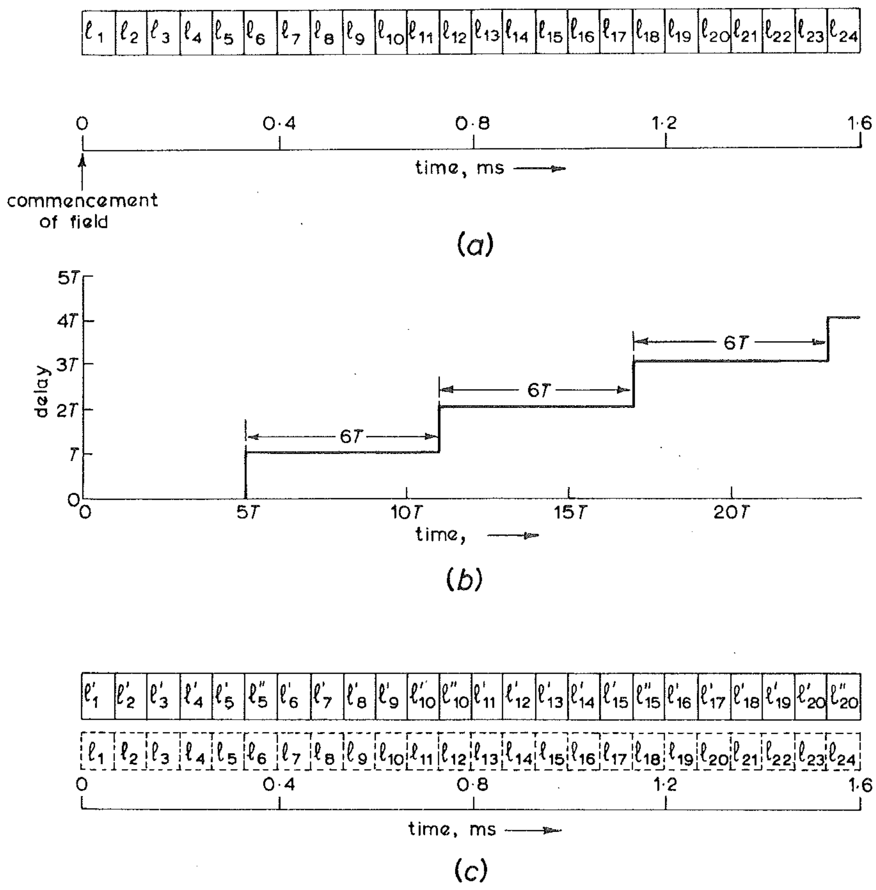


Fig. 6 - 250/60 to 300/50 field sequential conversion: conversion of first 24 lines of first output field

(a) Input lines ($66\frac{2}{3}$ μs duration)
(b) Delay introduced by main store ($T = 66\frac{2}{3}$ μs)
(c) Output lines (input lines shown dotted for comparison)

APPENDIX III

Conversion between the British 625/50 and American 525/60 Standards

1. The Conversion Cycle

In Appendix II, conversion between standards with identical line durations is examined and it is pointed out that in this case, the conversion process can be achieved by the repetition or omission of an appropriate number of lines in each input field. In turn, the fact that it is merely necessary to repeat or omit lines enables the conversion to be achieved by switching delays equal to the duration of a line into or out of the main store. In the practical case of interest, the line lengths are not identical but are very similar (64 μs for the British 625/50 standard and $63\frac{31}{63}$ μs for the American 525/60 monochrome standard). This similarity of line length enables conversion to be achieved with a system similar to that described in Appendix II, but with the addition of a correcting circuit.

Since it will be necessary to add or subtract lines from the incoming standard, it is first necessary to determine the occasions in the conversion cycle at which the addition or subtraction must occur. This can be done by superimposing rasters of the same dimensions at the two standards.* The superimposed rasters will exhibit a spatial beat pattern of line position such that at intervals two lines of the 625/50 standard will fall between two adjacent lines of the 525/60 standard; the phenomenon must, in fact, occur 50 times during each field. Each time two lines of 625/50 standard fall between two lines of the 525/60 standard, a line must be omitted (if the input standard is 625/50) or added (if the input standard is 525/60). At the end of each output field, the total number of units of delay added or subtracted must therefore be equal to the difference between the number of lines per field of the two standards since a unit of delay must be introduced or removed each time a line is repeated or omitted. A total of 50 units of delay must therefore be introduced or removed and the total delay of these units must be equal to the difference in field duration of the two standards. The unit of delay must therefore be:

$$T = \left(\frac{1}{50} - \frac{1}{60}\right)/50 \text{ s} = 66\tfrac{2}{3}\ \mu s$$

Since the line durations of the two standards are only approximately equal to 'T', small timing errors will occur in the sense that the output line signals, after passing through the main store, will start at times slightly different from their required starting times. These errors in starting time will reach a maximum of about 3 μs during any output field and must be corrected by an additional circuit following the main store.

* It may be shown that it is permissible to suppose that one of the rasters has been sheared slightly so that the scanning lines of both rasters are exactly parallel

So far as the field-by-field operation is concerned, the sequence of events for 525/60 to 625/50 and for 625/50 to 525/60 will be as shown in Figs. 4 and 5 respectively. However, as in the cases considered in Appendix II, the scale is too small to show that the delay variations are discontinuous and not smooth. To illustrate the conversion process, therefore, Fig. 7 shows timing diagrams covering the

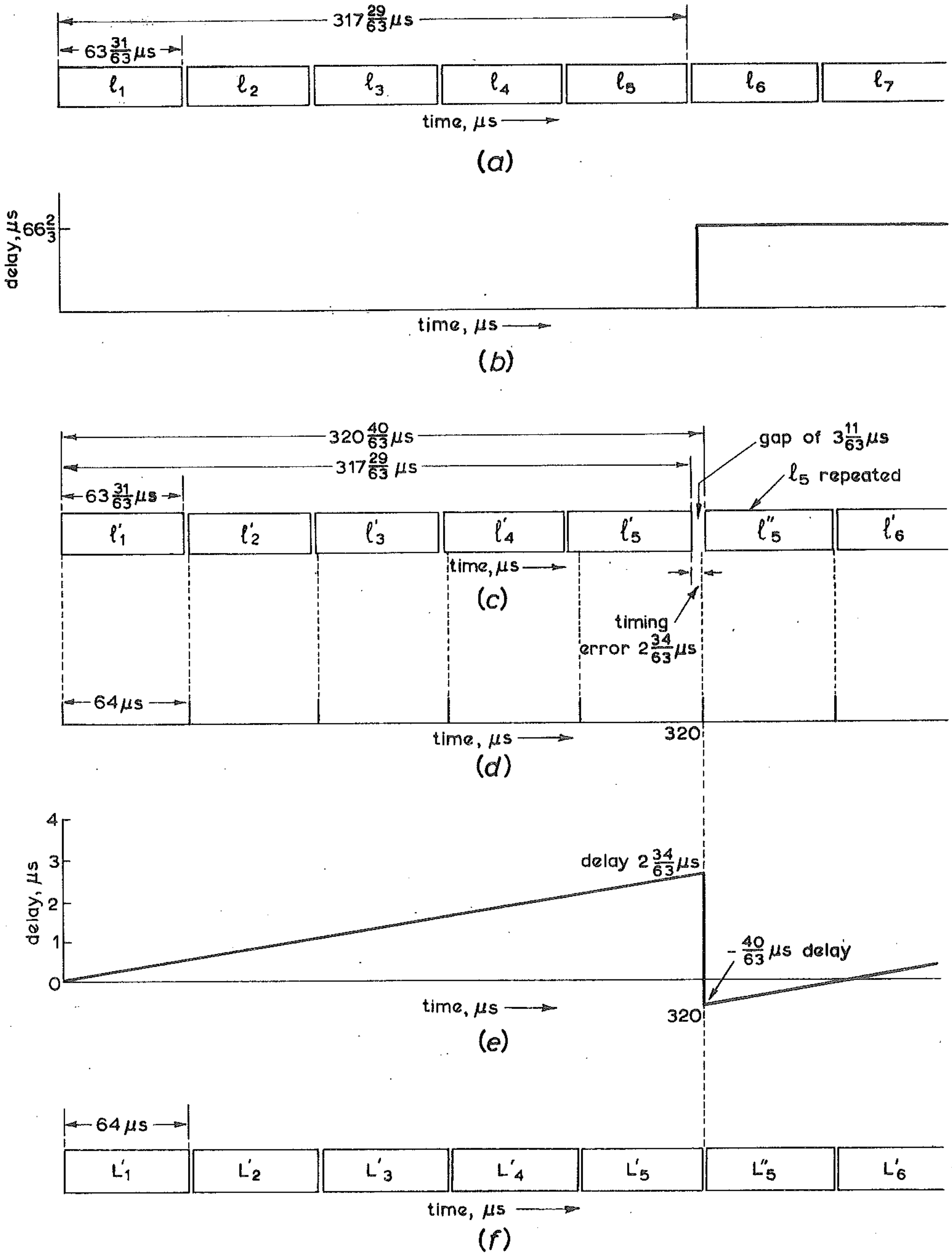


Fig. 7 - 525/60 to 625/50 conversion:
conversion of first seven output lines of first output field

(a) 525/60 input lines
(b) Delay introduced by main store
(c) Output lines from main store
(d) 625/50 output line-synchronising pulses
(e) Variable delay after main store
(f) 625/50 output lines

period of the first seven input lines in the first field of a cycle of six input fields for the case of 525/60 to 625/50 conversion. In Fig. 7, it is assumed that output synchronising pulses are added after the signal has been passed through both the main store and the line-timing error-correcting circuit.

Fig. 7(a) shows the sequence of seven lines l_1 to l_7 at the input standard and Fig. 7(b) shows the delay introduced by the main store. For the duration of the first five input lines, the delay is zero, and is then switched to 'T' ($66\frac{2}{3}$ μs). Fig. 7(c) shows the sequence of lines emerging from the main store and the output standard synchronising pulses are shown in Fig. 7(d). It will be seen that by the end of the fifth output line, l'_5, Fig. 7(c), an error in timing relative to the synchronising pulses of $320 - 317\frac{29}{63}$ μs ($2\frac{34}{63}$ μs) has occurred. The insertion of the delay of $66\frac{2}{3}$ μs introduces a gap of $3\frac{11}{63}$ μs between the end of the fifth output line l'_5, Fig. 7(c), and the commencement of the sixth output line l''_5 which is a repetition of the fifth input line. The presence of the gap of $3\frac{11}{63}$ μs slightly over-corrects the accumulated error and there is an error of only $\frac{40}{63}$ μs in the time of commencement of l''_5.

It should be noted that the addition of a unit of delay 'T' (and the resulting repetition of a line) does not occur at regular five-line intervals; the sequence of lines is actually 5, 5, 5, 6, etc. At the end of each sequence of six lines, the insertion of the delay 'T' introduces a gap which exactly corrects the accumulated timing error. Fig. 7(e) shows the delay introduced by the variable delay network to correct errors in the timing of the lines emerging from the main store and Fig. 7(f) shows the output from the variable delay. For convenience, the variable delay is shown as introducing both positive and negative delays; in practice, of course, this network would introduce a fixed delay and the first output line L'_1 would be retarded in time relative to the first input line l_1.

Fig. 7 illustrates a conversion from the 525/60 standard to the 625/50 standard. The reverse case of a conversion from 625/50 to 525/60 can be carried out in a similar manner but the units of delay (T) would be progressively removed from the store as the cycle proceeds. The converter could therefore be made 'bi-directional', provided that the main store had a total delay equal to the duration of a field of the standard with the lowest field frequency (625/50). The sequence of events in a conversion from 625/50 to 525/60 would be similar to that shown in Fig. 7, except that instead of the gap shown in Fig. 7(c) between groups of lines emerging from the main store, there would be an overlap each time a unit of delay T were switched out and a line omitted. These overlaps would be corrected, and the lines correctly timed by a variable delay network as in the case of the 525/60 to 625/50 conversion.

In the case of both 525/60 to 625/50 and 625/50 to 525/60 conversion, the variable delay network would be controlled by the difference in timing of the lines emerging from the main store, and the synchronising pulses on the output standard. The output standard synchronising pulses would, of course, be derived from the input standard synchronising pulses.

2. Interpolation

The conversion cycle described in Section 1 of this Appendix would result in a distorted output picture due to the omission of lines (in a 625/50 to 525/60 conver-

sion) or the repetition of lines (in a 525/60 to 625/50 conversion). The distortion can, however, be considerably reduced by using an interpolation process similar to that employed in line-store standards conversion. However, since the principles of interpolation have already been described,[2] only aspects particular to field-store conversion will be discussed. The interpolation process could, in principle, be carried out either before or after the main store. It is most convenient instrumentally, however, to carry out the interpolation at the input standard before the signal enters the main store and this arrangement will be assumed in this Appendix.

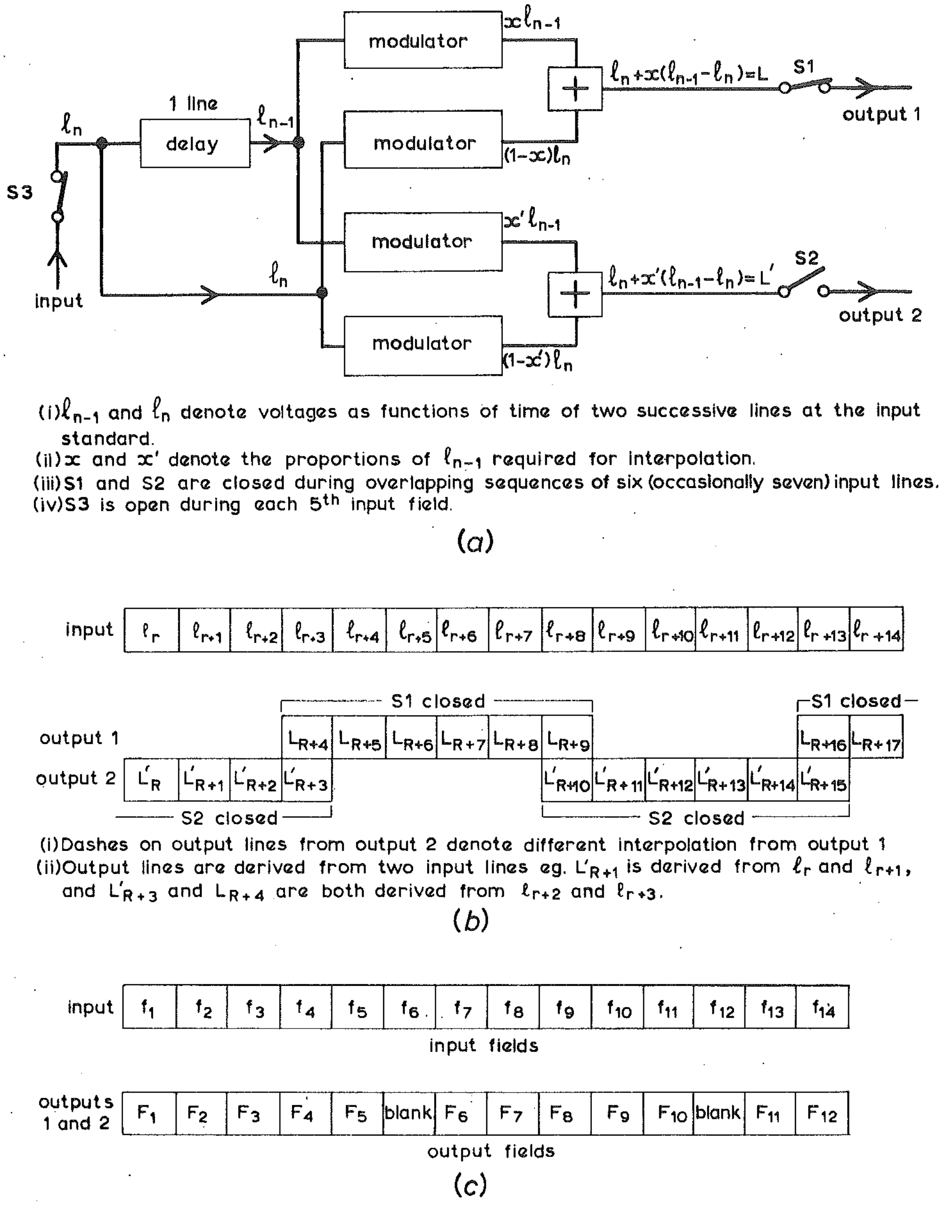


Fig. 8 - Interpolation process for 525/60 to 625/50 conversion

(a) Schematic of interpolator
(b) Typical sequences of input lines and interpolated output lines
(c) Sequences of input and output fields

Interpolation between adjacent lines of a field at the input standard requires that signals corresponding to two successive lines are made available simultaneously. This can be achieved by means of a one-line delay, and a new line signal is derived by taking weighted proportions of the signals corresponding to the two lines.

2.1. 525/60 to 625/50 Conversion

During the period of each field at the input standard, there will be fifty occasions on which the interpolator must produce two lines simultaneously so that fifty new lines are added to each 525/60 field. This simultaneous generation of the lines will occur at intervals of five or six lines at the interpolator input. The sequence is 5, 5, 5, 6, 5, 5, 5, 6, etc., so that during each of the incoming lines numbered 5, 10, 15, 21, 26, 31, 36, 42, etc., the interpolator produces two output lines and 25 lines leave the interpolator for every 21 lines entering it. It is important to note, however, that when two lines are produced simultaneously by the interpolator they cannot be identical since they will eventually occupy different spatial positions on a display of the output standard. The interpolation arrangement is illustrated schematically in Fig. 8(a) and is seen to have two outputs which produce successive sequences of six (and occasionally seven) lines. The sequences of six (or seven) lines from the two outputs overlap as shown in Fig. 8(b) so that six (or seven) lines emerge from the interpolator during the duration of five (or six) input lines. The interpolator is also arranged so that every sixth field at the input standard is discarded as illustrated in Fig. 8(c); this is necessary since five fields at the output standard occupy the same duration as six fields at the input standard.

2.2. 625/50 to 525/60 Conversion

Fig. 9(a) shows the interpolator arrangement* for this conversion in which the two outputs deliver successive sequences of six fields (instead of successive sequences of six or seven lines as in the case of 525/60 to 625/50 conversion). In the signal from each of these outputs, each sixth or seventh line of each input field must be discarded in order to reduce the number of lines per picture from 625 to 525. The sequence is 6, 6, 6, 7, 6, 6, 6, 7, etc., so that the interpolated output signal must comprise sequences of five or six interpolated lines, each sequence being followed by a 'blank' of line duration. This is illustrated in Fig. 9(b) which shows the corresponding sequences of lines at the input and output of the interpolator. Six output standard fields must, however, occupy the duration of five input standard fields and during the duration of every fifth input field, the interpolator must therefore produce two fields simultaneously. It must be noted, however, that although the two simultaneous interpolated fields are both generated from every fifth input field, they are not identical since they will eventually be interlaced to form a complete picture at the output standard and their spatial positions will therefore differ on an output display. Thus the two fields must be derived simultaneously from different proportions of the two input line signals available in the interpolator.

* For simplicity, Figs. 8 and 9 show a pair of modulators associated with each interpolator output. Each pair of modulators could, however, be replaced by a single modulator as used in the BBC Research Department line-store standards converter. The modulator would operate on the difference signal $l_{n-1} - l_n$ and give a signal $x(l_{n-1} - l_n)$ which when added to l_n would give the correct interpolated output. Thus in practice, only two modulators are required in the interpolator.

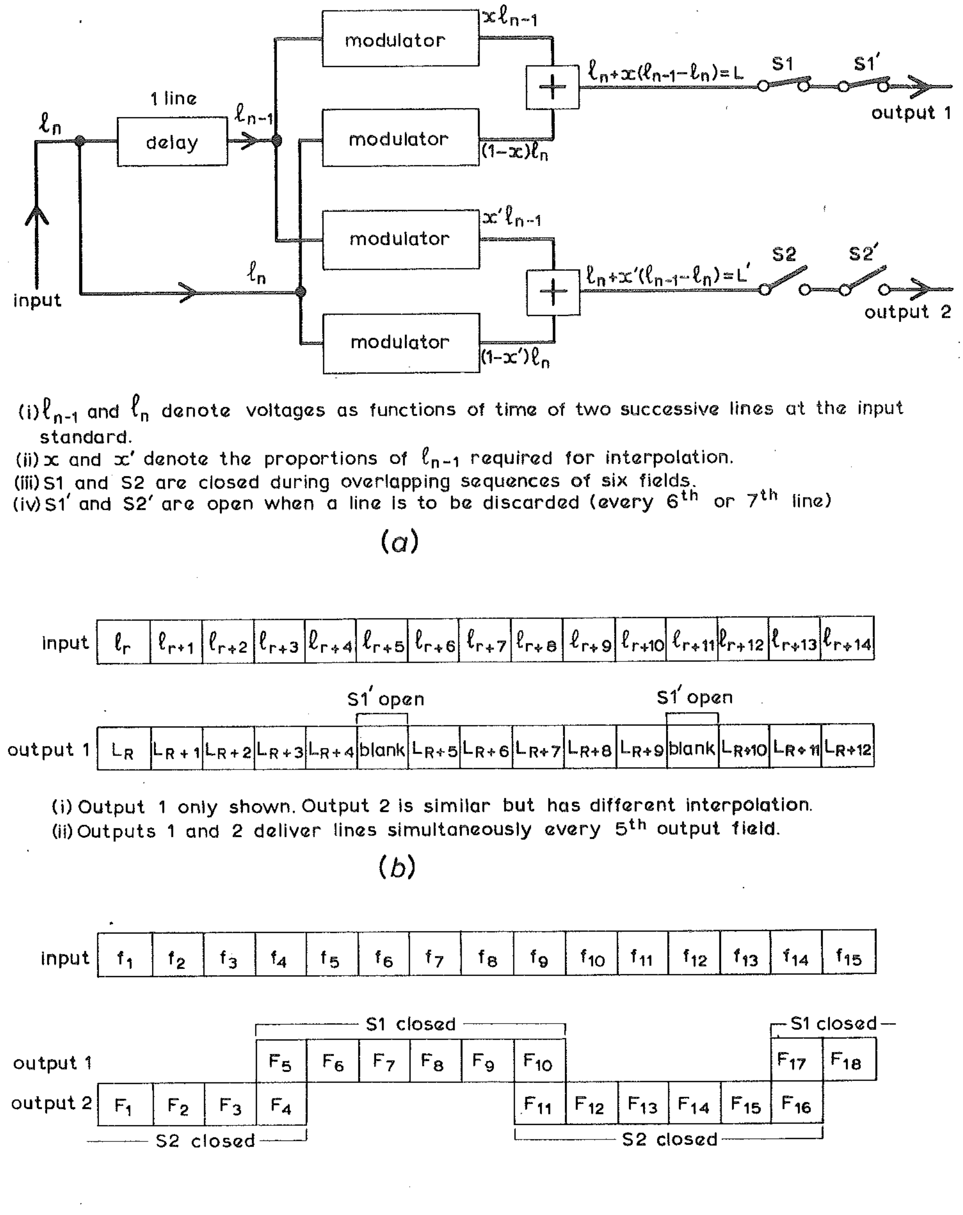


Fig. 9 - Interpolation process for 625/50 to 525/60 conversion

(a) Schematic of interpolator
(b) Typical sequences of input lines and interpolated output lines
(c) Sequences of input and output fields

Fig. 9(c) shows the relation between the fields at the input of the interpolator and the fields leaving the interpolator. The two outputs of the interpolator are arranged to deliver over-lapping sequences of six fields so that six fields leave the interpolator during the duration of five input fields.

2.3. Interlacing

Interlacing affects the design of the field-store converter in three ways:

(i) Steps must be taken to achieve a correctly-interlaced picture at the output

standard. For example, as illustrated in Fig. 9(c) for the case of 625/50 to 525/60 conversion, a sequence of six fields at the output standard is derived by interpolation of a sequence of six consecutive input fields. The six output fields in this sequence are thus correctly interlaced. However, the last output field of this sequence and the first output field of the next sequence of six fields are derived from the same input field. Thus without some form of timing correction, each sequence of six output fields will not be interlaced with the preceding, and succeeding sequences.

(ii) It is necessary to derive from a given type of input field (say an even field) both odd and even interpolated fields. Suppose, for example, that the input field f_3 of Fig. 9(c) is an odd field and that the output field F_3 derived from f_3 is also an odd field. Then in the next sequence of six input fields, f_7 is an odd field but F_8 which is derived from it must become an even field.

(iii) It has already been pointed out in Section 1 of this Appendix that the occasions on which the addition and subtraction of lines must be made can be determined by superimposing rasters of the same dimensions at the two standards. If the raster of a particular field at the output standard (say an even field) is superimposed on the rasters of even and odd fields at the input standard, the spatial beat pattern of line position will differ. The positions on the raster at which two lines of one standard fall between two lines of the other will differ and thus the omission or insertion of lines in the output signal must be made at different times in the conversion cycle.

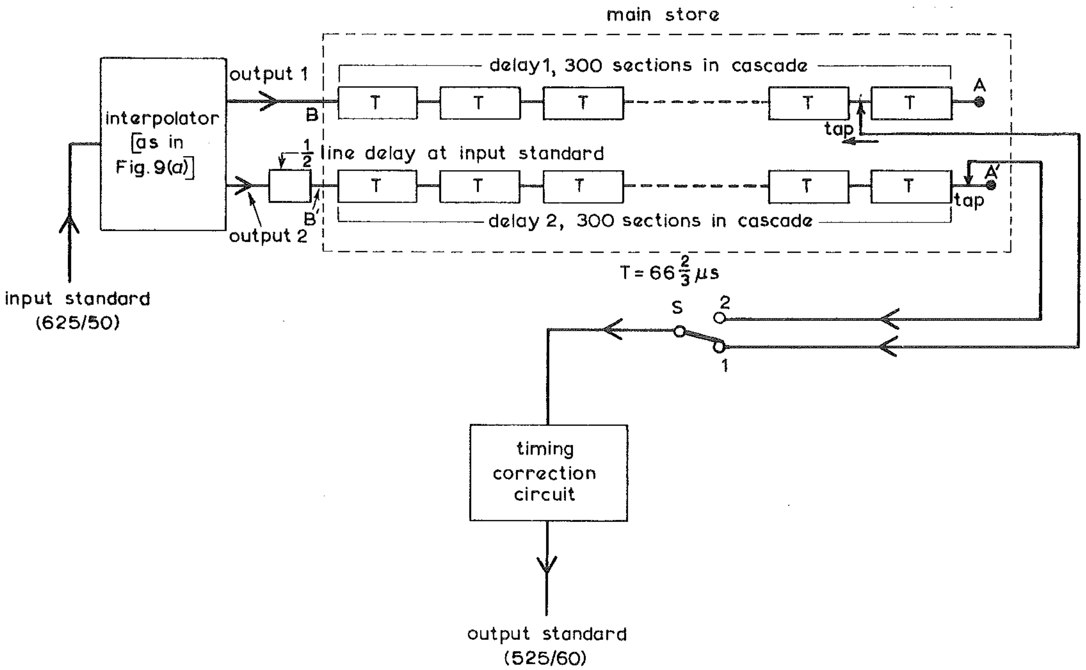


Fig. 10 - Outline of 625/50 to 525/60 conversion using interpolator and switched main store

The manner in which the difficulties outlined in (i), (ii) and (iii) above can be overcome may be illustrated by reference to conversion from the 625/50 to the 525/60 standard. In the arrangement shown in simplified form in Fig. 10, the two outputs of the interpolator of Fig. 9(a) are connected to two tapped delays, each comprising 300 sections of delay T ($66\frac{2}{3}$ μs). Two tapped delays are shown only to simplify the explanation; in practice, only one delay would be required.

The first of a sequence of six interpolated fields from output 1 of the interpolator is first stored in delay 1. During the duration of the next five interpolated fields from output 1, the tap on delay 1 progresses from point A to point B reducing the delay from '300T' to zero, and six fields emerge from the tap during this period. The delay is reduced by 'T' each time it is necessary to discard a line and thus 50 units of 'T' are introduced during the duration of each field appearing at the tap.

Simultaneously with the emergence of the last of the sequence of six interpolated fields from output 1, a field emerges from output 2 and is fed into delay 2. At the conclusion of the sixth output field, this field is completely stored in delay 2 and at this instant the switch S is changed from position 1 to position 2. The tap on delay 2 then progresses from point A' to point B' during the duration of the next five input fields and produces the next sequence of six output fields. It will be seen that a delay of the duration of a half-line at the input standard is connected in cascade with delay 2. The function of this additional storage element is to achieve a correct interlace of the successive sequence of six fields at the interpolator output. A proof that the arrangement of Fig. 10 will deliver correctly interlaced and interpolated output fields requires a detailed examination of the passage of each field through the interpolator and main store. Such a detailed examination is beyond the scope of this report, but it can be shown that:

(a) Successive sequences of six fields from the two interpolator outputs, (1) and (2) in Fig. 10, can be correctly interlaced by the inclusion of the additional 'half-line' delay in cascade with one of the main-store delays. In Fig. 10, this delay is shown in cascade with delay 2.

(b) Different forms of interpolation can be provided by the two interpolators 1 and 2 in Fig. 10 which enable one interpolator to derive the scanning lines required for even (odd) interpolated fields from even (odd) input fields and the other to derive the scanning lines required for odd (even) interpolated fields from even (odd) input fields. The additional 'half-line' delay in cascade with delay 2 then gives a correct interlace as mentioned in (a) above.

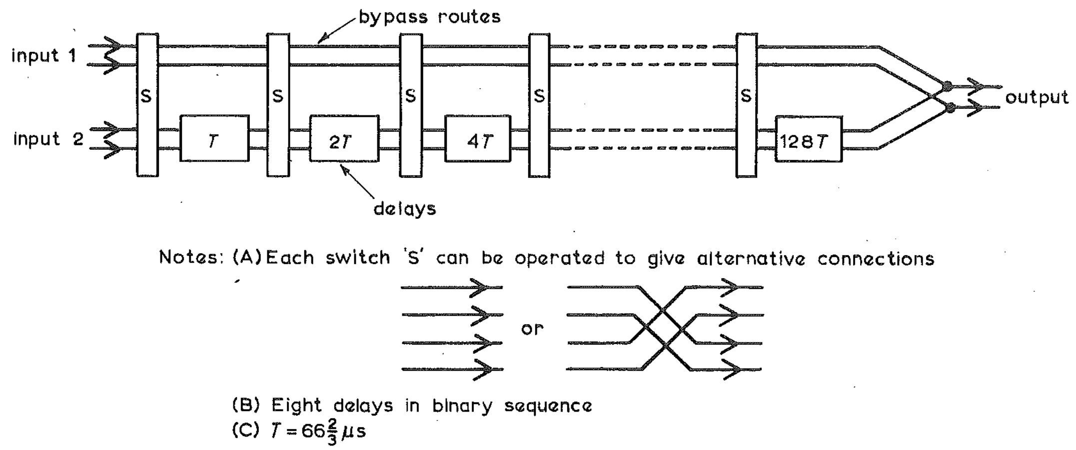
(c) Although, as has already been pointed out, the occasions during a field period at which a line must be discarded differ for the two interpolator outputs, it is possible to arrange the switching sequences of delay 1 and delay 2 to accommodate this requirement. Thus each of the main-store delays 1 and 2 in Fig. 10 will change from '300T' to zero during the period of five input (six output) fields. Each time a delay is reduced by 'T', one line will be discarded, a total of 50 lines being discarded in each input field.

3. The Switched Delay Arrangement for the Main Store

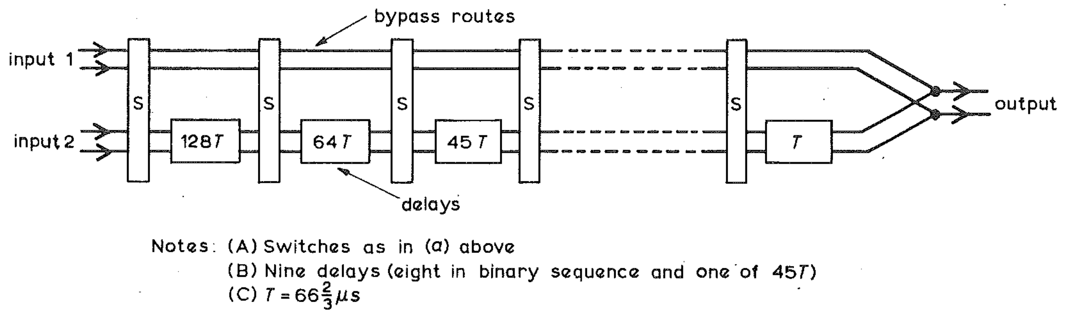
The conversion process described in Sections 1 and 2 of this Appendix requires that the main store must be equivalent to a delay of the duration of one field of the input standard and tapped at regular intervals of T ($66\frac{2}{3}$ μs). Thus the greatest delay will be required when the input standard is 625/50, and will be 20 ms. If the main store were, in fact, a delay of 20 ms tapped at intervals of $66\frac{2}{3}$ μs, a total of 300 sections would be required. Such an arrangement would be impracticable but an arrangement using a relatively small number of fixed delays with a suitable form of switching can be arranged to perform the same function. A suitable arrangement is one based on the binary system in which M separate units are used which have delays of:

$$T,\ 2T,\ 4T\ \ldots\ldots\ 2^{M-1}T$$

Selections of these M units can be arranged to give integral multiples of the delay 'T' from unity up to 2^M-1, i.e. delays of T, $2T$, $4T$ .... (2^M-1) T. A



(a)



(b)

Fig. 11 - Arrangement of binary main-store

(a) Main-store arrangement for 525/60 to 625/50 conversion
(b) Main-store arrangement for 625/50 to 525/60 conversion

set of nine delay units with delays of T, $2T$ .... $256T$ would give a delay up to $511T$ but a more economical arrangement to give delays from 0 to $300T$ may be obtained by replacing the '$256T$' delay with a '$45T$' delay. The arrangement of this modified binary store is shown in Fig. 11(a) and Fig. 11(b); the delays are arranged in series and connected by switches, so arranged that each unit can be either inserted between the input and output terminals or can be by-passed.

In describing the operation of the binary delay store, it is convenient to consider first the case of 525/60 to 625/50 conversion which is described in Section 1 of this Appendix and illustrated in Fig. 7. The input signal for the main-store will be provided by the interpolator and, as explained in Section 2 of this Appendix, the interpolator will produce two lines simultaneously at five- or six-line intervals. The arrangement of the binary store provides two pairs of input terminals (see Fig. 11(a)) which enables two lines generated simultaneously by the interpolator to be inserted simultaneously. It can be shown that, using the switching arrangement of Fig. 11(a), the store will accept all the scanning lines delivered by the interpolator without any two lines ever being fed simultaneously into the same delay or by-pass route. Each scanning line on reaching a switch can either be routed through the delay following the switch or can, alternatively, by-pass that delay and it can be shown that if the switches are operated at the correct times, each scanning line will travel by a route providing the exact delay required. The exact delay required, of course, is that necessary to re-arrange the overlapping sequences of lines delivered by the interpolator so that they emerge from the main-store in sequence.

The case of 625/50 to 525/60 conversion differs from the converse in that the interpolator now delivers two interpolated fields simultaneously during the duration of every fifth input field. In addition, any given field emerging from the interpolator will have blank lines at intervals of six or seven lines. It can be shown that the main-store arrangement of Fig. 11(b) will meet the demands of this conversion since it will:

(a) Delay the lines of each field so that the gaps formed by the blank lines are removed and the active lines emerge in steady sequence.

(b) Accept simultaneously the two fields generated by the interpolator at intervals of five input fields. The store will process the field required first in the sequence of output fields as in (a) above whilst it simultaneously stores the other. When the processing of the first field has been completed, and it has emerged from the store, the second (stored) field is then processed as in (a) above.

APPENDIX IV

The Correction of Timing Errors in the Output Signal

It is essential that the signal provided by the field-store converter should comprise a sequence of lines commencing at epochs that are evenly-spaced by the duration of one scanning line at the outgoing standard. Any failure in this respect would cause geometrical errors in the pictures displayed on receivers. The precise timing accuracy required for the output lines would have to be determined by subjective experiments, but it is likely that the timing of the commencement of each scanning line would have to be made correct to within about ± 5 ns.

Errors in timing will arise from three causes. In the first place, there will be an error varying systematically from line to line as a result of the difference between line durations on the two standards. This error will be corrected only once in every 21 (525/60) or 25 (625/50) outgoing scanning lines; between corrections it will vary between 0 and $2\frac{34}{63}$ μs, or 0 and $3\frac{3}{63}$ μs, according to the direction of conversion.

Errors will result also from instability in the individual delays used and it may not be possible to avoid these errors completely by the use of accurate thermostatic control of the ambient temperature of the delays. The third source of error is variation in the incoming line frequency which would affect the magnitude of the systematic error referred to above and would make it difficult to make a correction by a 'programmed' system.

In view of the large number of delay conditions required, the best method of correcting all the errors is thought to be to use a single correcting unit at the output of the store. This unit would compare the line synchronising pulses emerging from the main-store with a locally-generated set of equally-spaced synchronising pulses and control a variable delay so as to bring the two sets of pulses into coincidence. No distinction need then be made between the systematic errors inherent in the conversion process and errors which cannot be predicted. It would appear reasonable to provide a correction with a total range of 4 μs, of which about 0·5 μs would be available for correcting errors in the delays and in the incoming line frequency. Assuming the error in the delays of the main-store to be negligible, then the incoming line frequency could be permitted to depart from the nominal value by 25 parts in 10^4.

The delay correction must be able to reduce errors of ± 2·0 μs to within ± 5 ns; in other words, errors must be reduced by a factor of 400. It is probable that the best solution would be to use switched storage units similar to those employed in the Research Department line-store converter. This converter employs 576 stores, but about 60 stores would be sufficient for achieving a delay correction of up to 5 μs. The stores would operate in a cyclic order with the timing of writing determined by locally-generated synchronising pulses at the output standard. Such an

arrangement could effect the required reduction in the errors in a single operation. It is worth noting also that by extending the storage capacity of the timing-correction store to the duration of a full active line length (approximately 540 stores) and by modifying the switching logic of the main-store, the converter could be made capable of a much wider range of timing-correction. This possibility is mentioned in Section 5 of the main body of this report and it is pointed out that it would then be possible to convert between signals whose field frequencies are locked to local sources, i.e. the input and output field frequencies can vary independently of each other.

The provision of switched storage units similar to those used in the line-store converter would be expensive and an investigation of simple techniques of timing correction would be worthwhile. A closed-loop servo system would obviously suggest itself but, unfortunately, could not be employed since the error can vary discontinuously from line to line. A simple open-loop system similar to the Amtec arrangement used in the Ampex videotape recorder could not possibly correct to the accuracy required because the devices that measure and correct the timing errors would require time voltage laws matched to one part in 400. A possible solution would be to use a number of open-loop servo systems in cascade. Assuming that these are all of the continuously-variable type, reliability demands that every one system should not be relied upon to reduce the error by more than 5. Four stages in cascade would then be required, of which the first two would operate upon the line-synchronising pulses and the second two would require another signal (similar to the colour burst in the NTSC system) as a more precise time reference. A more satisfactory alternative might be to replace the first three stages of continuous timing control by a single digital timing control using either a tapped delay line or a switched series of binary delay units in cascade.

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey